Event-by-Event Fluctuations in Relativistic Heavy Ion Collisions

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The main motivation of building Relativistic Heavy Ion Collider (RHIC) is to find a new state of matter – Quark Gluon Plasma (QGP) – which have not been in existence since moments after the Big Bang. Since physics run at RHIC is expected to start within the year 2000, it is of great importance and urgency that we have clear signals of QGP. Our work establishes that event-by-event fluctuations in hadron multiplicity ratios can be such unambiguous signals of QGP.

In general, sudden changes in fluctuations signal a phase transition. For instance, if the system undergoes a second order phase transition, fluctuations in the temperature or the volume exhibit discontinuous behavior across the transition point. However, intensive thermodynamic quantities such as temperature or pressure are not easy to measure in relativistic heavy ion collisions. Extensive thermodynamic quantities such as the hadron multiplicities are not suitable for fluctuation studies in heavy ion collisions since their fluctuation is dominated by the volume fluctuation.

The ratios of hadronic multiplicities overcome both of these difficulties. First of all, it is relatively easy to measure: Particle identification is basic to any experiment. Second, it is independent of volume fluctuations since the volume factors cancel in the ratios on the *event-by-event* basis. The ratio fluctuations, therefore, provide a clean picture of the underlying system. Moreover, when chosen judiciously, the ratio fluctuations can provide a distinct signal of a phase transition.

The fluctuation in the multiplicity ratio can be in general written as

$$\left\langle \delta R_{12}^2 \right\rangle = \frac{\langle N_1 \rangle^2}{\langle N_2 \rangle^2} \left\langle \left(\frac{\delta N_1}{\langle N_1 \rangle} - \frac{\delta N_2}{\langle N_2 \rangle} \right)^2 \right\rangle$$

where $\langle \cdots \rangle$ denotes the average over all events and we defined $R_{12} = N_1/N_2$ and

$$\delta x = x - \langle x \rangle \ .$$

The correlation term $\langle \delta N_1 \delta N_2 \rangle$ can be non-zero only if there are resonances that decay into both particle species at the same time. Using this fact, one can measure the resonance content at the chemical freeze-out.

In the letter published in Physical Review Letter[1], we first established that when the average multiplicities $\langle N_1 \rangle$ and $\langle N_2 \rangle$ are very much different from each other, then the above analysis cannot say much about the underlying system. This is because the ratio fluctuation in that case is dominantly driven by the fluctuation in the smaller quantity. For instance, π/K ratio fluctuation is driven by the fluctuation in the Kaon number, and hence does not provide much information the underlying system. The charged pion ratio π^+/π^- is much better suited in this regard.

Using the charged pion ratio fluctuation, we then estimated the abundance of the primordial ρ^0 and ω mesons. Our estimate indicates that according to the usual chemical freeze-out scenario, the fluctuation in π^+/π^- should be smaller by 30 % compared to the uncorrelated thermal gas of pions (i.e. the mixed events). The reduction mainly comes from ρ and ω mesons that provide correlation between π^+ number and π^- number. In view of the current CERES dilepton data, it is important that we made an independent estimate of the abundance of ρ and ω since these mesons are a big part of the dilepton sources.

Looking ahead, anomalously large or small fluctuation at RHIC can indicate that the system is not in hadronic chemical equilibrium – possibly signaling a new state of matter.

Footnotes and References

[1] S. Jeon and V. Koch, Phys. Rev. Lett. **83**, 5435 (1999)